MINIMIZING LCOH WITH ADVANCED PROTON EXCHANGE MEMBRANES

Hydrogen Production
23rd October, 2024

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Together, improving life

GORE

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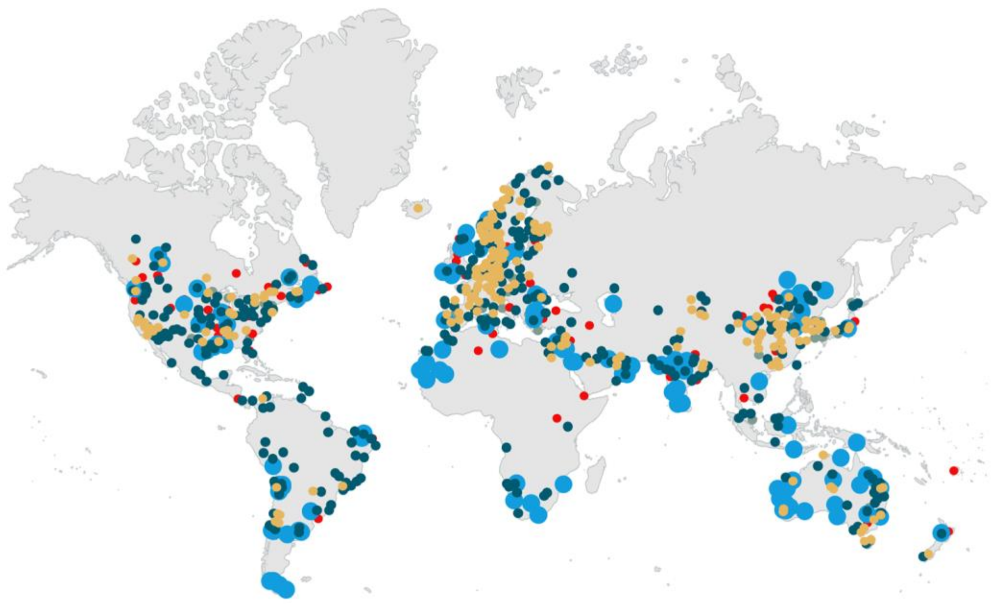
Gore’s PEM promise

HEADWINDS IN HYDROGEN PRODUCTION

The clean hydrogen project pipeline is growing & maturing, but deployment must accelerate rapidly to meet climate goals

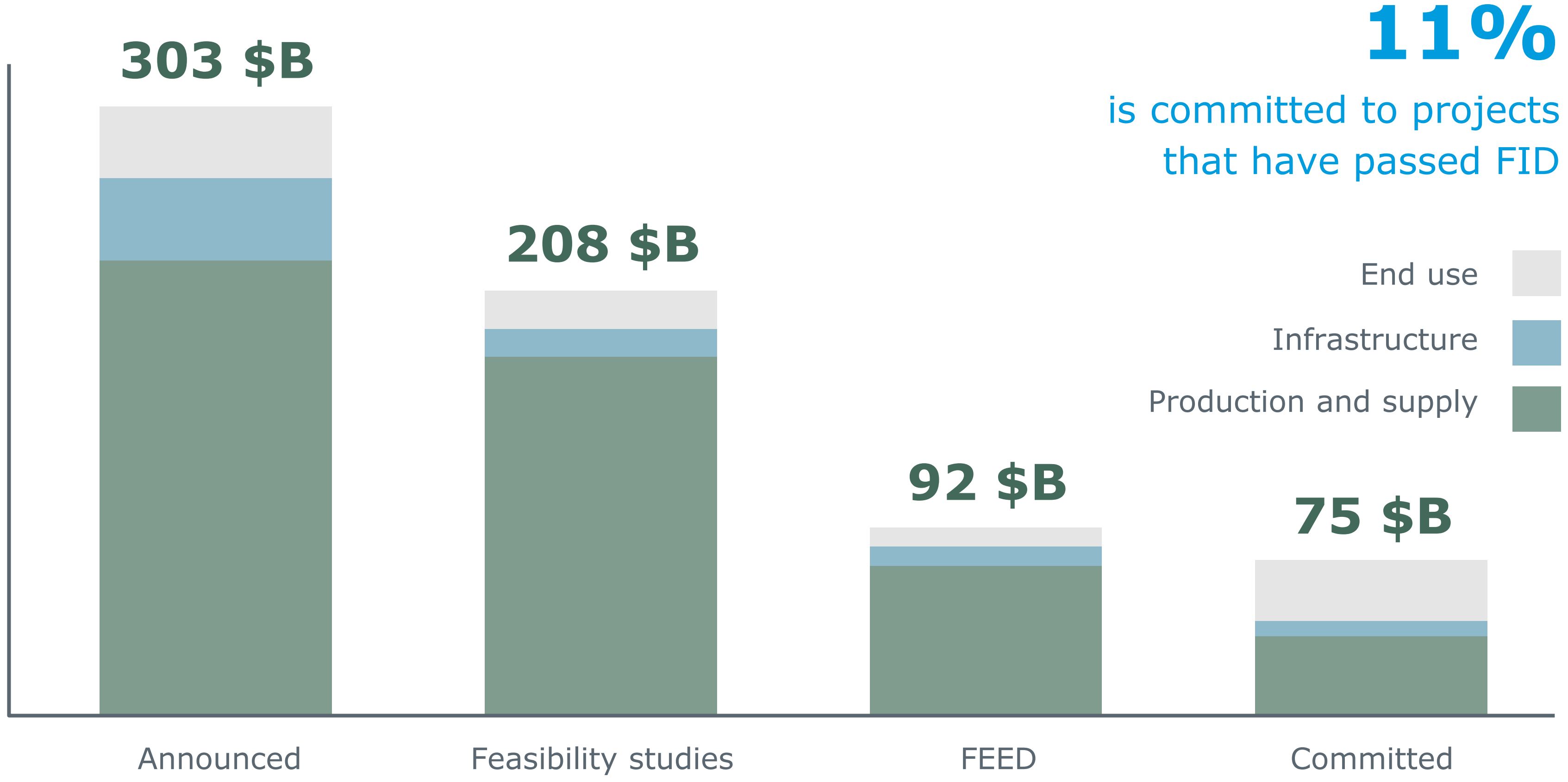
Hydrogen projects announced globally



1,572 hydrogen projects

- **186** Giga-scale production
- **783** Large-scale industrial use
- **268** Mobility
- **190** Integrated H_2 economy
- **138** Infrastructure projects

Direct hydrogen investments until 2030



Only 11% is committed to projects that have passed FID

- **1,572 clean hydrogen projects** announced globally as of May 2024
- **434 projects (about 28% of total)** have passed FID stage

- **USD 678 billion in direct investments** in clean H_2 projects have been announced through 2030
- **Just over 11% (USD 75 billion) is committed to projects** that have passed FID

Hydrogen Insights 2024, Hydrogen Council, 2024, https://hydrogencouncil.com

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Headwinds for hydrogen projects

The clean hydrogen industry faces significant cost challenges.

Three key factors driving project development:

1 Finding and Certainty of Demand

- Securing stable and long-term demand is critical for justifying investments in hydrogen projects.
- Offtakers cannot commit due to a lack of long-term pricing mechanisms.

2 Power Prices

- Competitive and predictable energy prices are essential for cost-effective hydrogen production.

3 Regulation

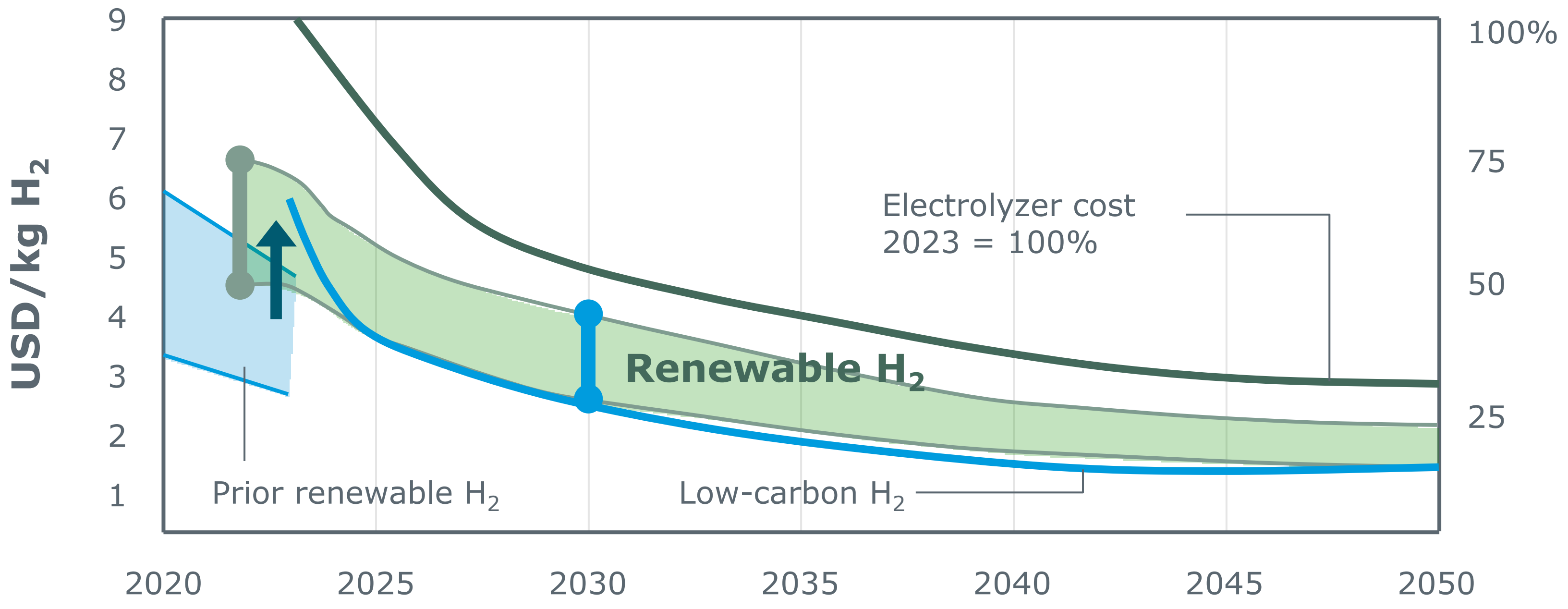
- Clear and supportive regulatory frameworks are necessary to facilitate project approvals and financing.

Development of levelized cost of hydrogen

~$4.5-6.5/kg current LCOH

+30-65% increase in LCOH driven by capex, financing and renewables costs

$2.5-4.0 cost target by 2030



Hydrogen Insights 2023, Hydrogen Council, 2023, https://hydrogencouncil.com

A lack of committed offtakers, high costs, and regulatory uncertainty are significant barriers preventing wider adoption and slowing down project development.

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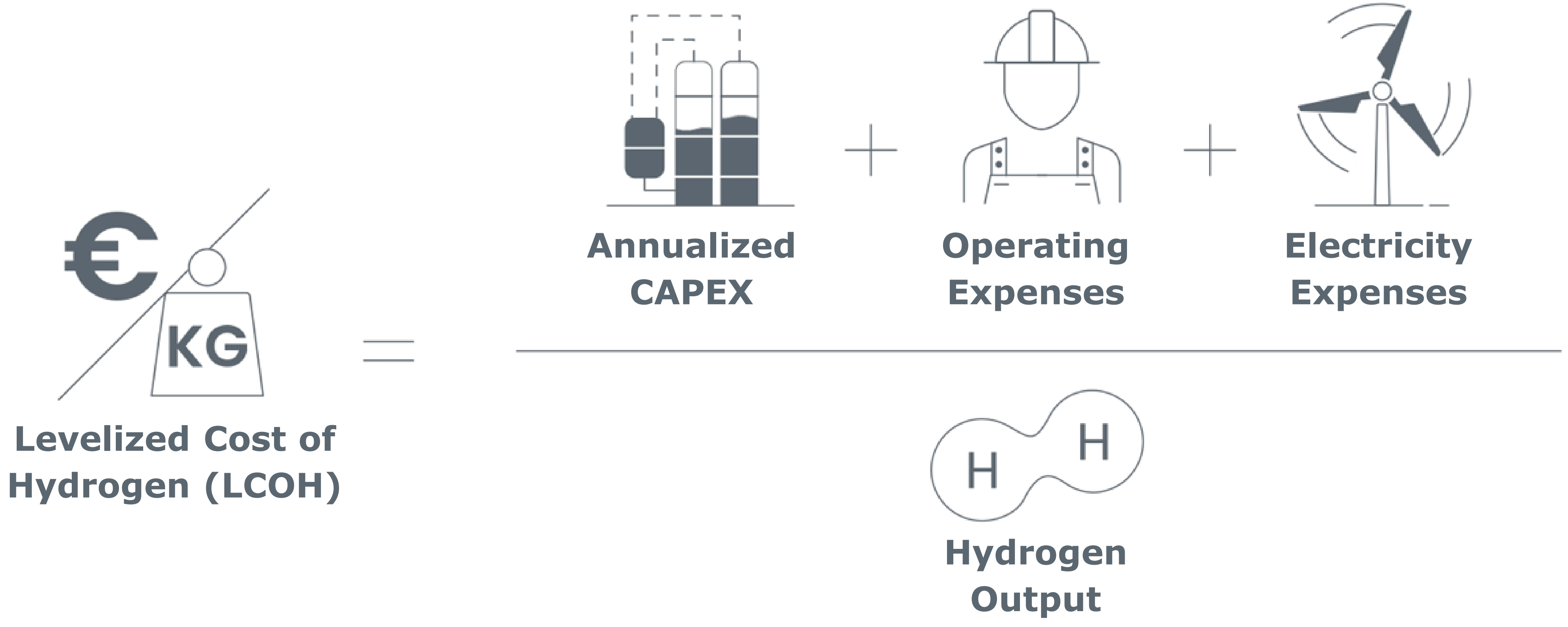
CALCULATING LCOH

LCOH is used to benchmark the cost-competitiveness of hydrogen production projects

There are many studies focusing on LCOH reduction considering different regional and economical factors.

However, as a leading PEM supplier, Gore wanted **to investigate PEM attributes and their impact on reducing LCOH.**



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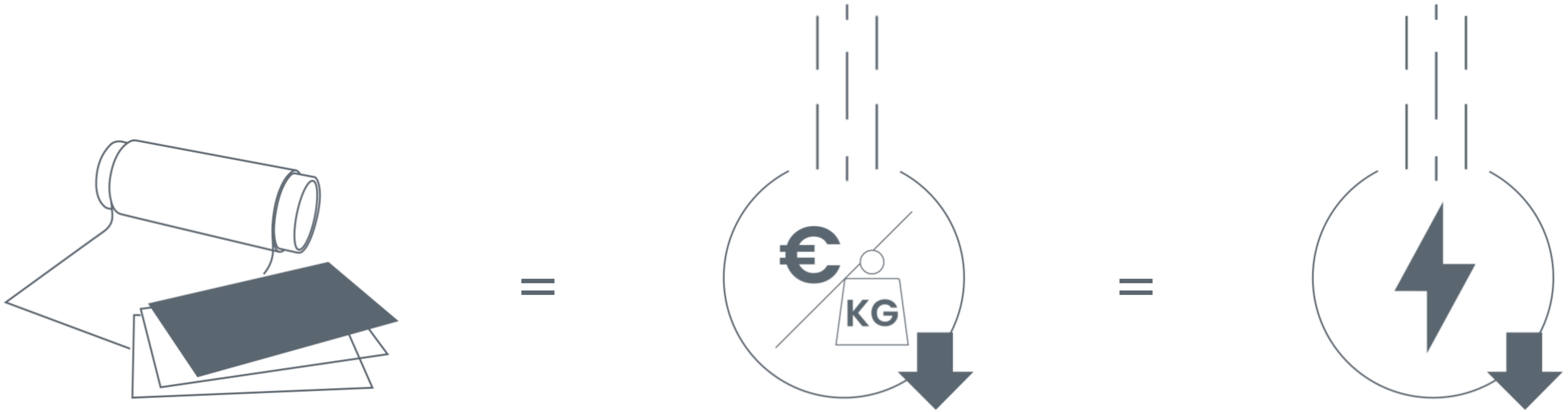
Developing a hypothesis

The right PEM can significantly reduce LCOH by lowering electricity costs.



Choosing the Right PEM = **Lowered Electricity Consumption** = **Reduced LCOH**

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Expanding that hypothesis

How? By increasing the efficiency of an electrolysis cell via these two PEM attributes:

1

Proton Resistance

2

Hydrogen Permeation Resistance

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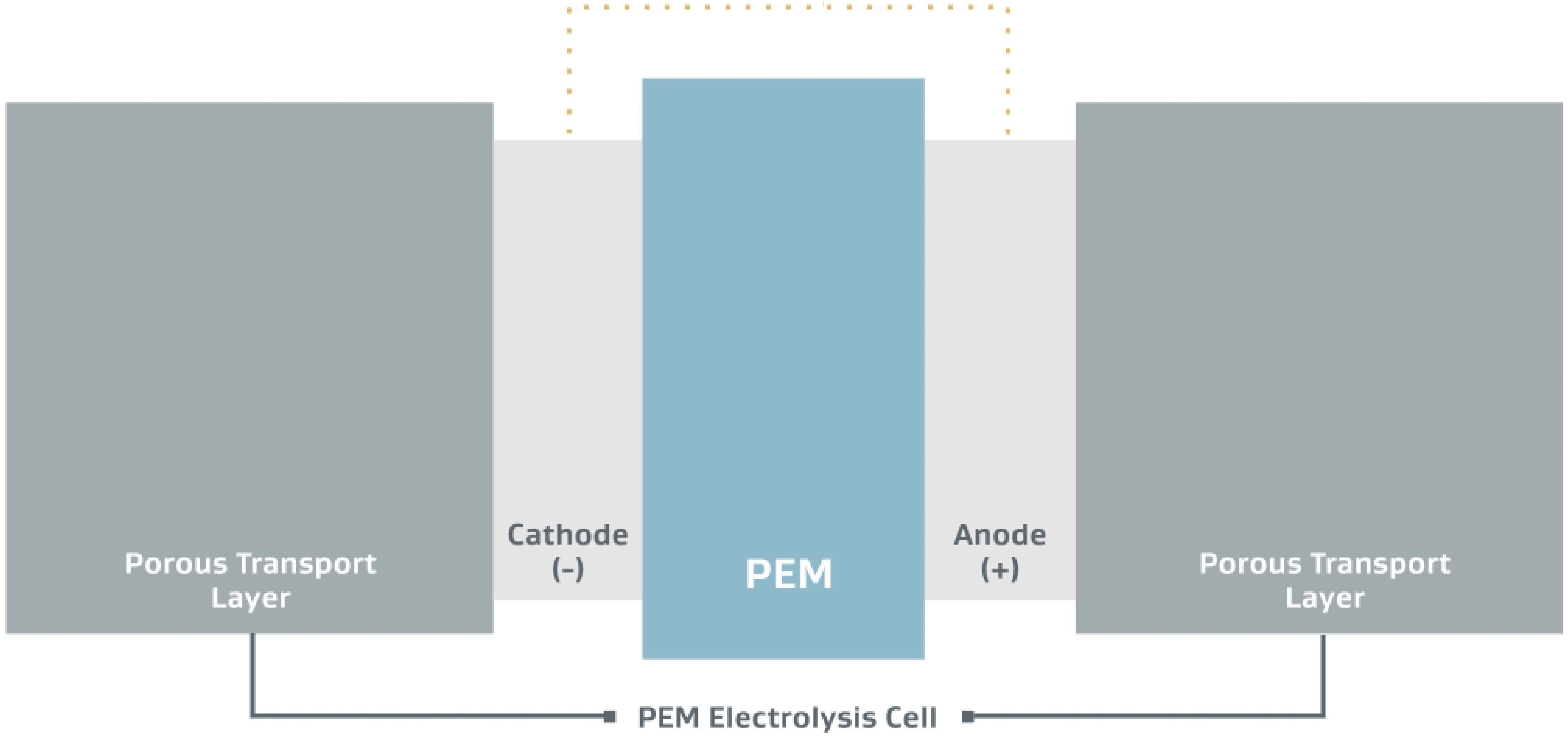
The lower the membrane proton resistance, the higher the cell efficiency

Proton Resistance

Hydrogen Permeation Resistance

Gore can engineer the membrane proton resistance by:

- reducing membrane thickness
- increasing ionomer conductivity



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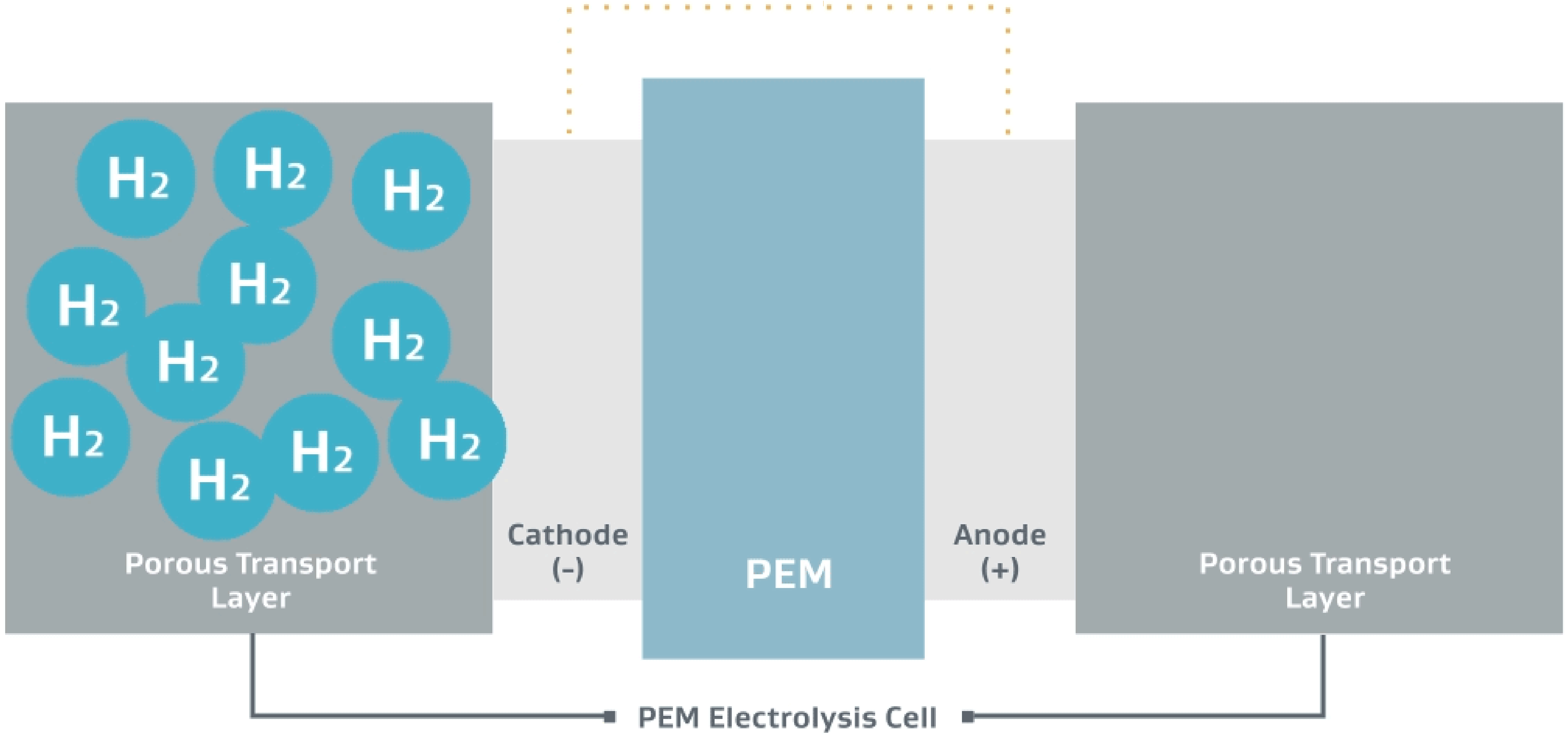
The higher the membrane hydrogen permeation resistance, the higher the cell efficiency

Proton Resistance

Hydrogen Permeation Resistance

Gore can engineer the membrane's H_2 crossover via:

- smart additives
- unique ionomers



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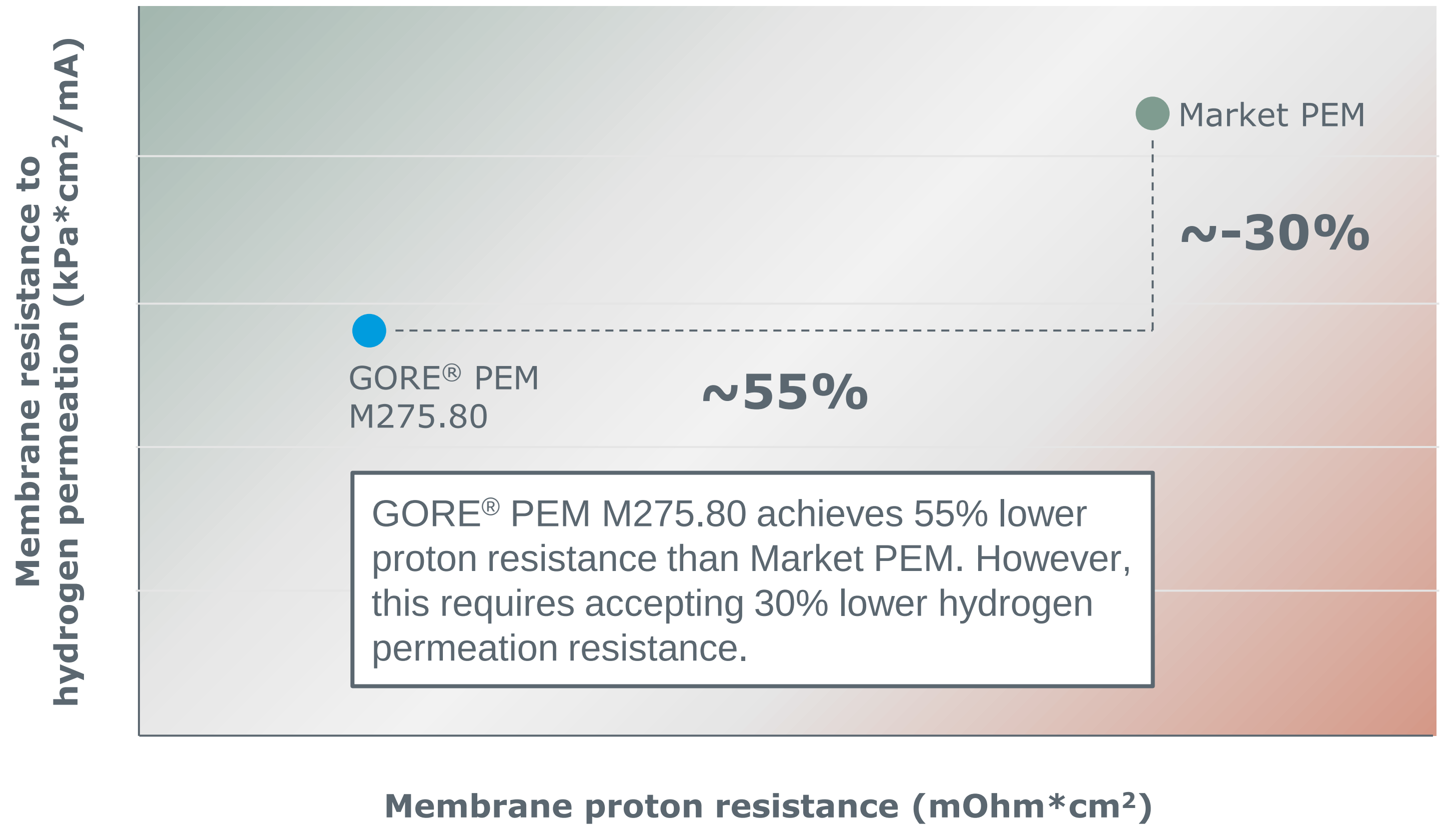
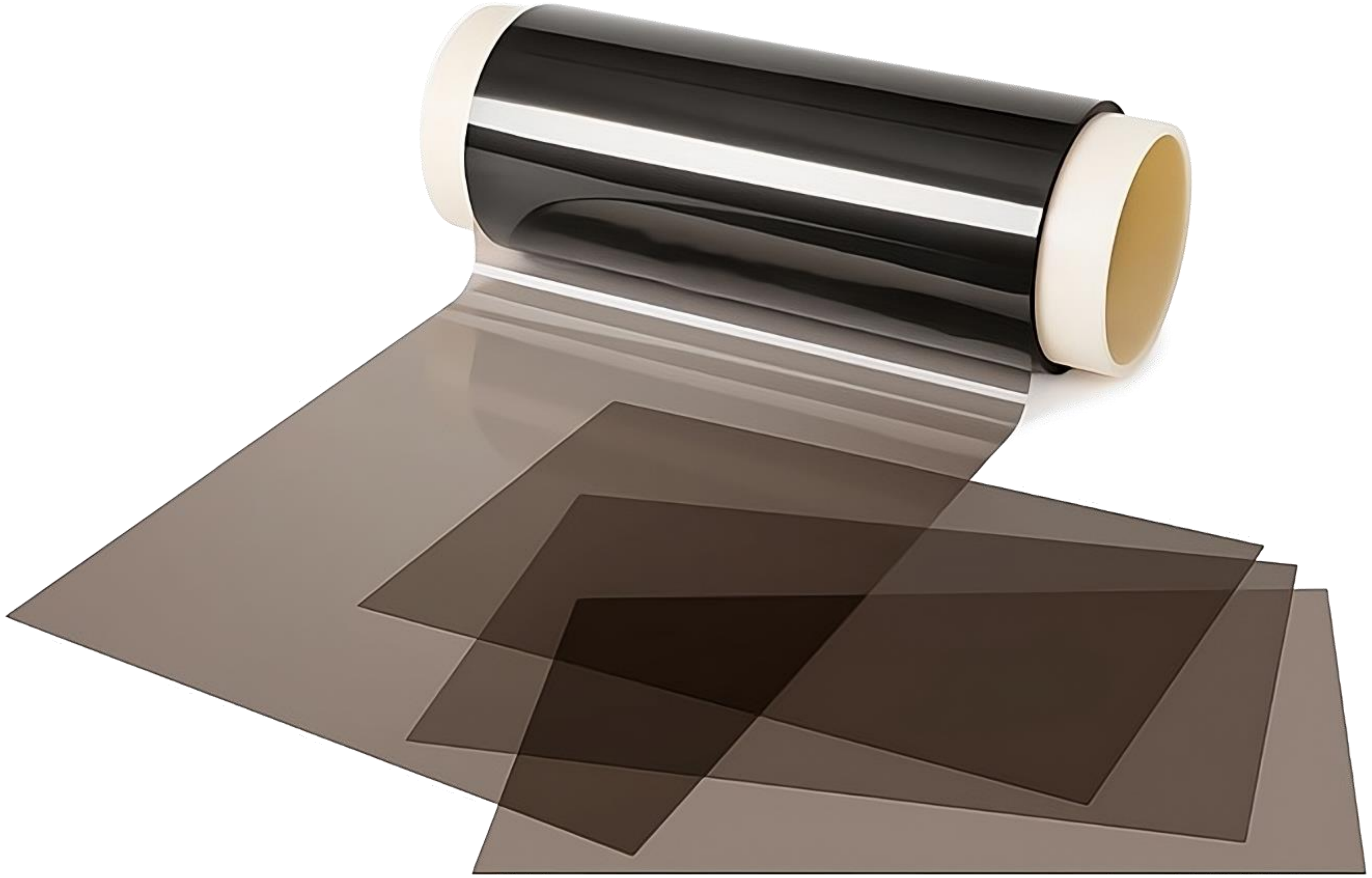
Breaking performance barriers with our advanced PEM technology

GORE® PEM M275.80 provides

- **superior proton resistance**
- **excellent permeation resistance**

to deliver improved overall cell efficiency.





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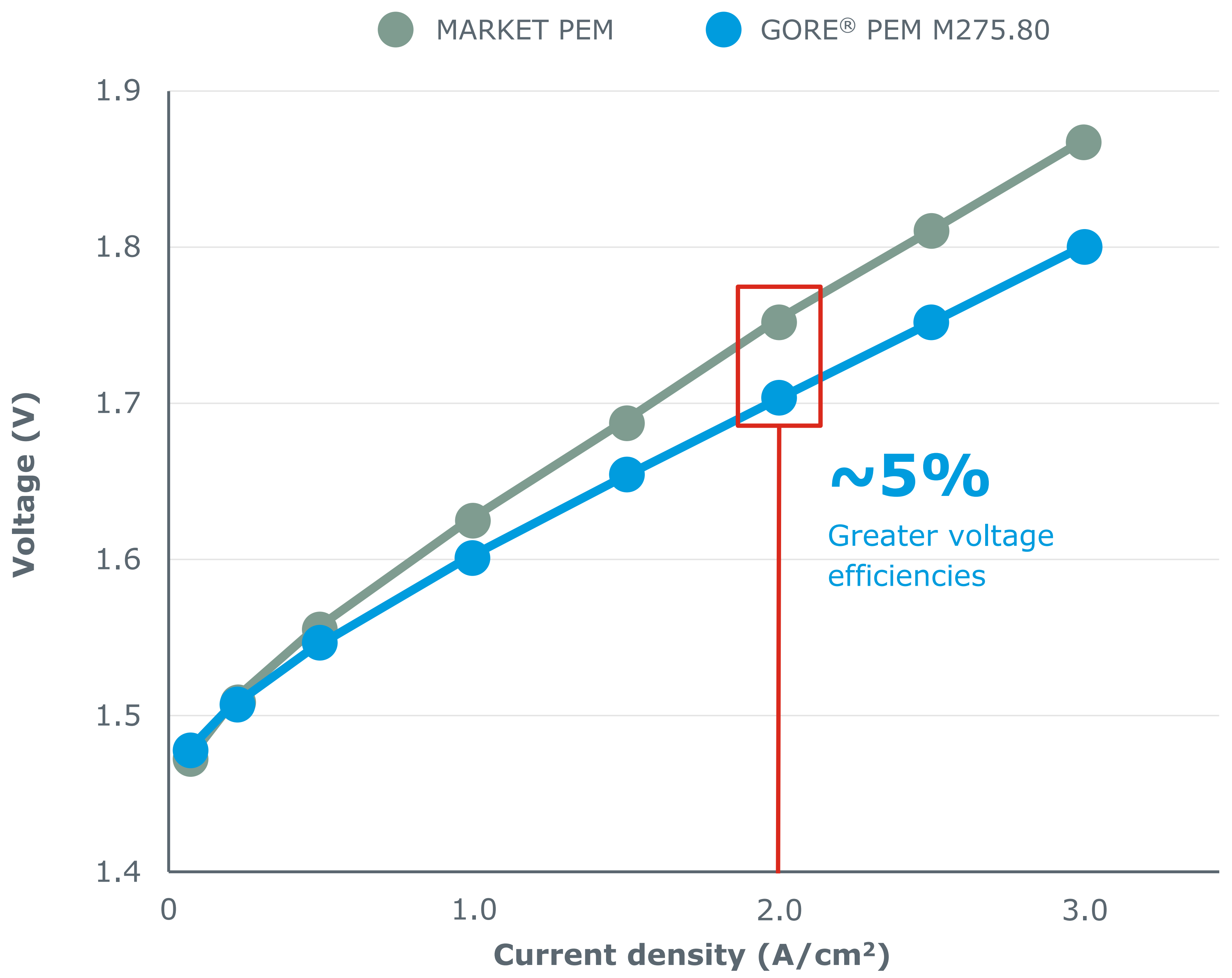
Increasing cell voltage efficiency. Reducing electricity consumption.

~5% **Greater cell voltage efficiencies.**

Gore’s PEM M275.80 offers ~5% greater cell voltage efficiencies over other PEM.

This reduces the amount of electricity required to produce 1 kg of Hydrogen by ~5%.



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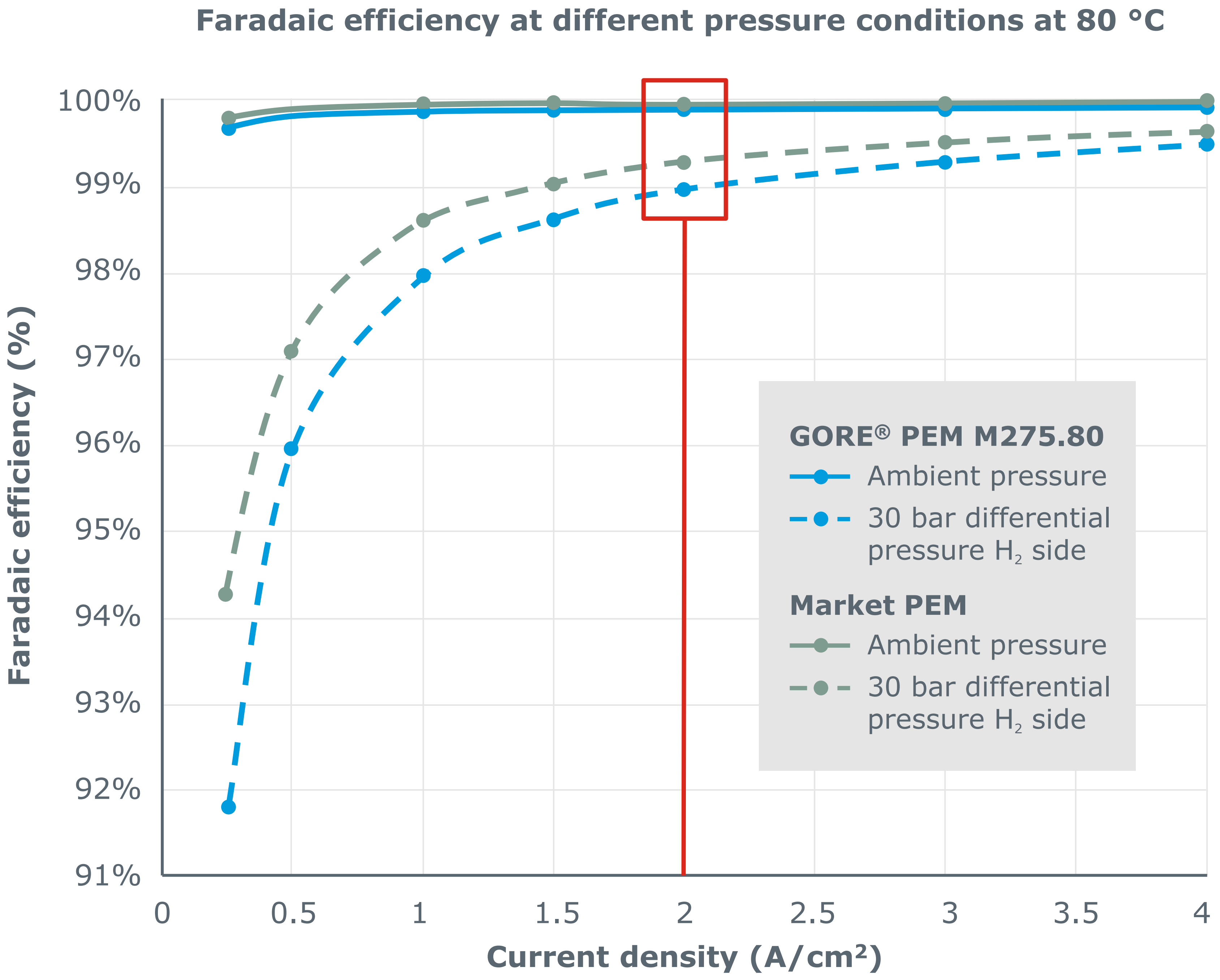
Balancing the Faradaic efficiency

~0.5% **Faradaic efficiency differential**

The difference in Faradaic efficiency between GORE® PEM M275.80 and Market PEM is <0.5% at 2 A/cm² and 30 bar.

Gore's balanced Faradaic efficiency has no significant impact on improving cell efficiency. The key driver for electricity savings is the PEM attribute proton resistance.



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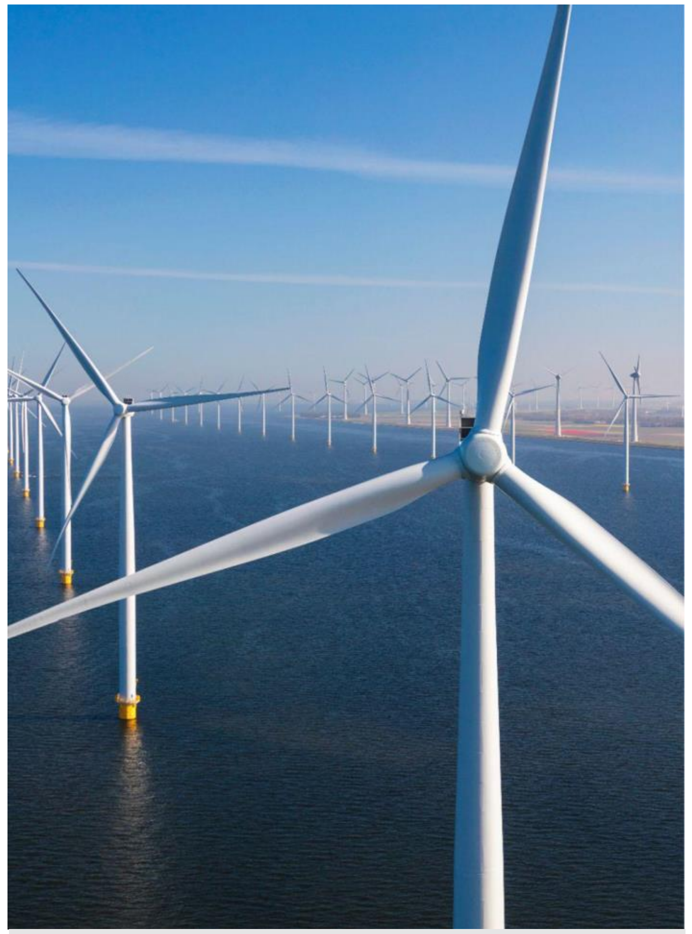
EXPLORING INDUSTRY USE-CASES

Conducting an industry-first investigation

GORE x FEV CONSULTING

Gore collaborated with FEV Consulting to prove that **Gore's PEM M275.80 provides the lowest LCOH** compared to an equivalent state-of-the-art PEM in three distinct use cases:



Offshore wind-powered H_2 production

H_2 in steel production

H_2 production hub for transport via PV

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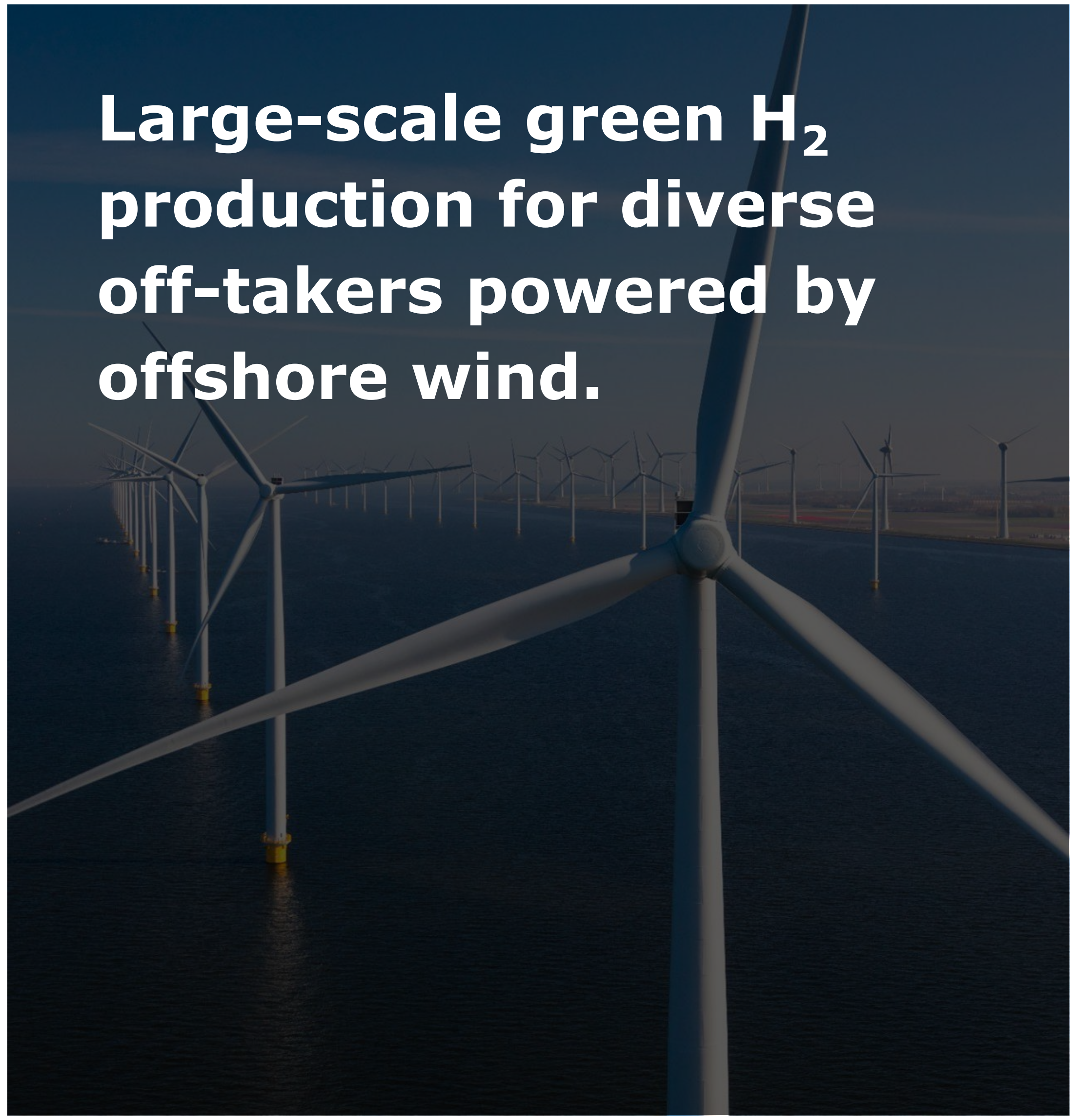
Use Case #1: Offshore Wind Farm

Use-case definition | System output | LCOH output | LCOH savings / year



- H_2 production for multiple off-takers
- Production: 11,400 tons of hydrogen/year
- Electrolyzer capacity: 100 MW
- PEM Electrolyzer system operated at differential pressure
- Power: Offshore wind
- Location: Germany
- Sale of O_2: €24.5/t

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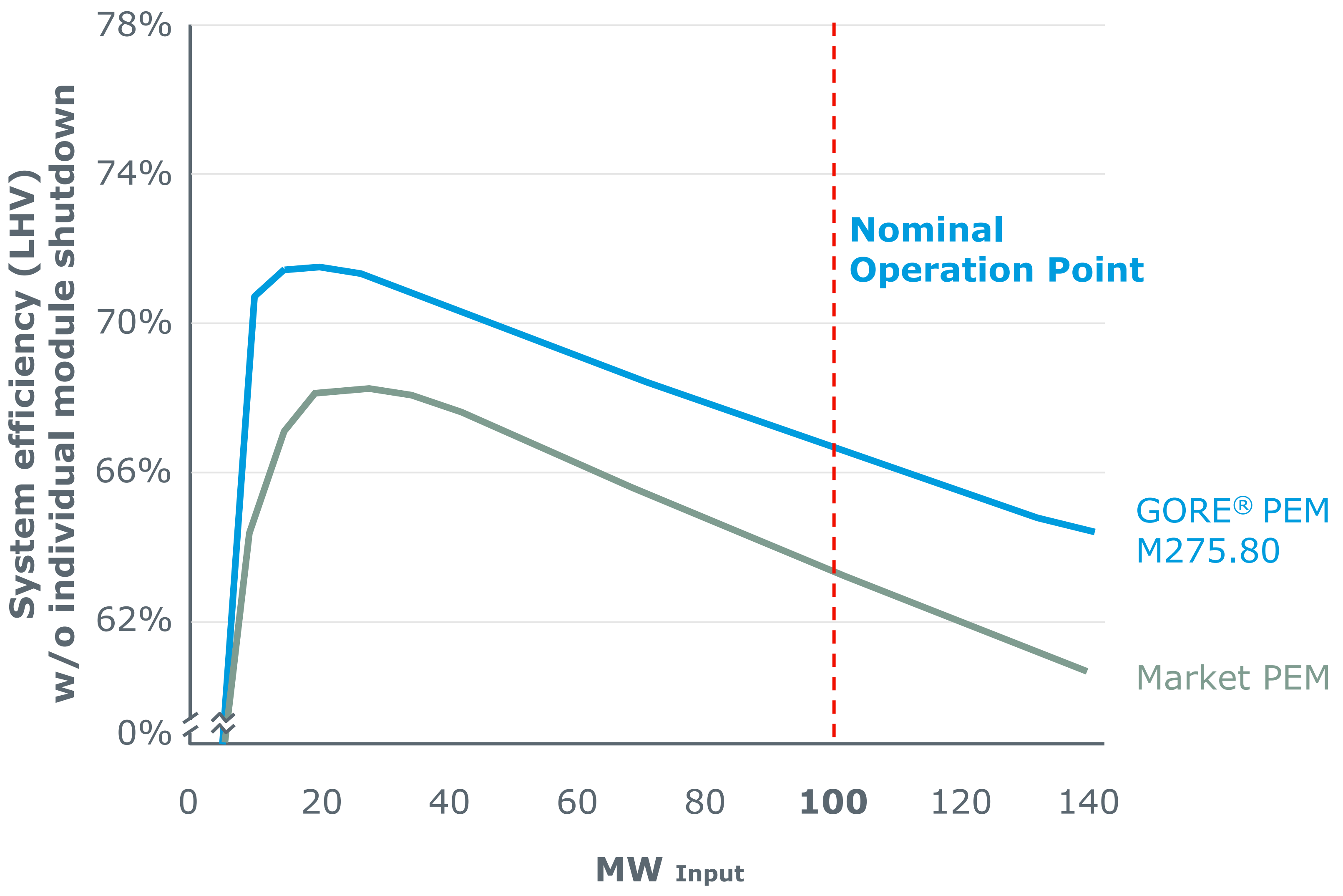
Use Case #1: Offshore Wind Farm

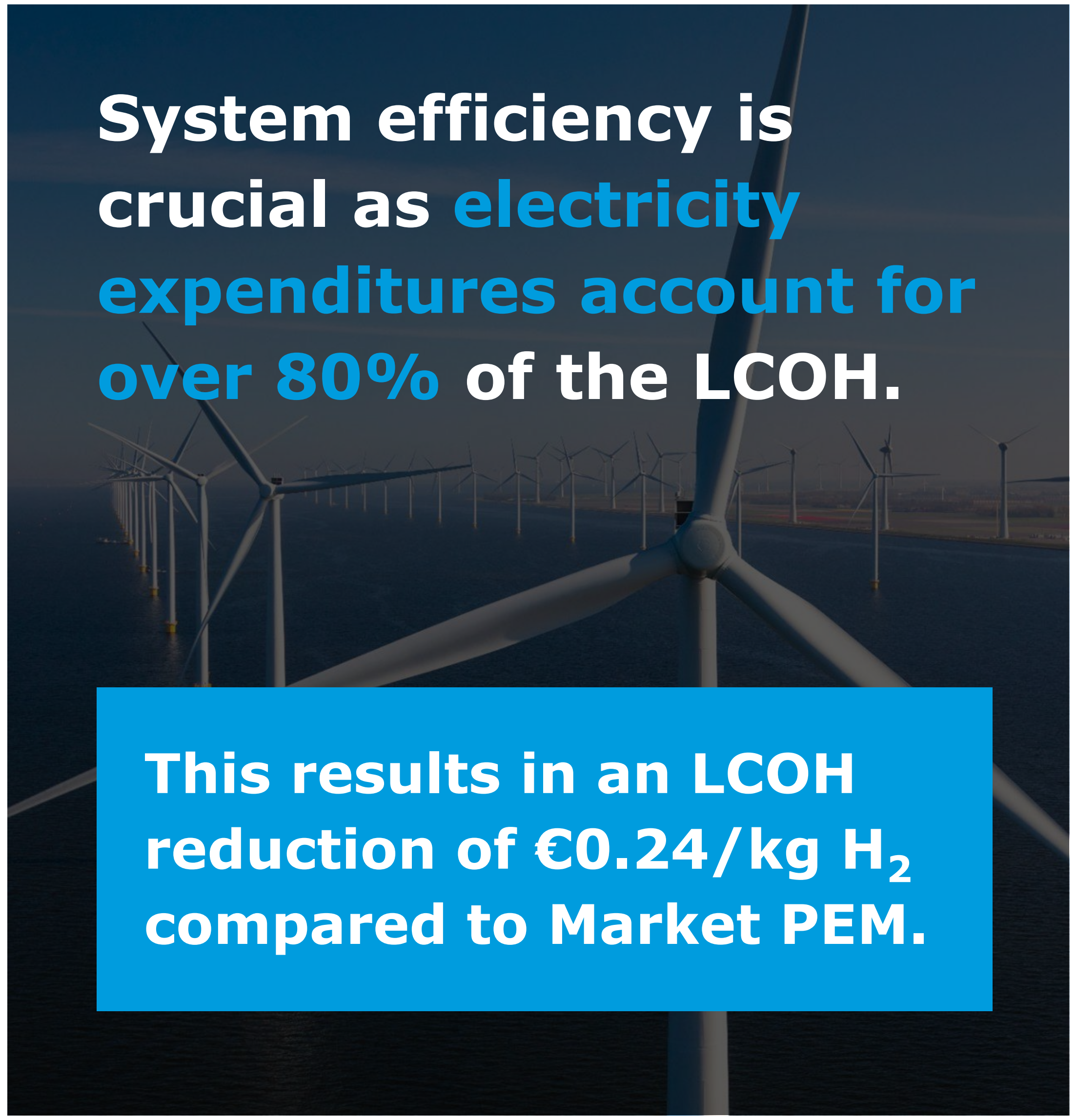
Use-case definition | **System output** | LCOH output | LCOH savings / year



Overall efficiency (LHV)	
GORE® PEM M275.80	**67.4%**
Market PEM	**64.1%**

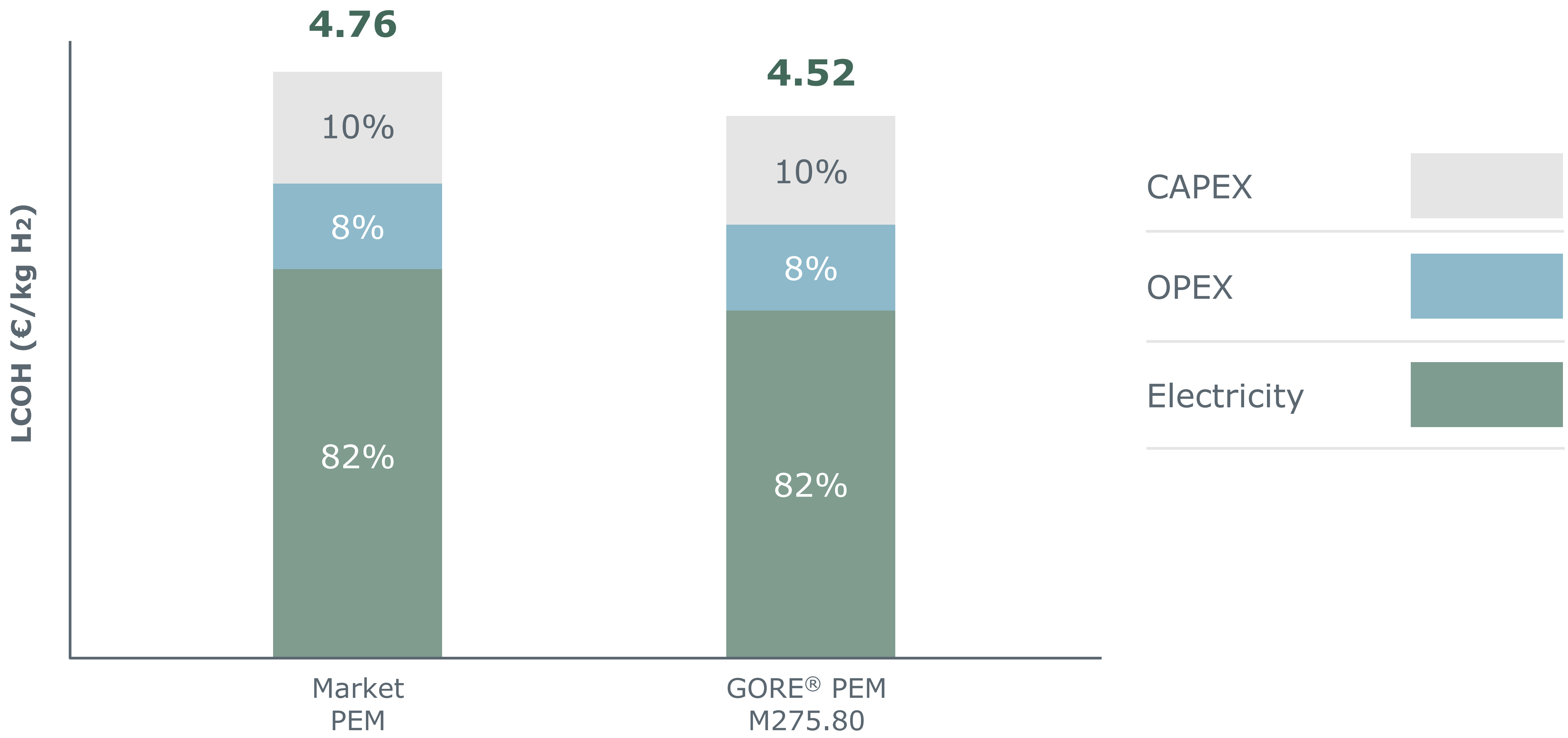
Use Case #1: Offshore Wind Farm

Use-case definition | System output | **LCOH output** | LCOH savings / year



System efficiency is crucial as electricity expenditures account for over 80% of the LCOH.

This results in an LCOH reduction of €0.24/kg H_2 compared to Market PEM.



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Use Case #1: Offshore Wind Farm

Use-case definition | System output | LCOH output | **LCOH savings / year**

€2.7 million

For an annual production of 11,400 tons at €4.52/kg H_2, this translates to yearly electricity savings of €2,700,000 compared to Market PEM.

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Use Case #2: Steel Mill

Use-case definition | System output | LCOH output | LCOH savings / year

- "Fixed" H_2 demand
- Production: 85,000 tons of hydrogen/year
- Electrolyzer capacity: 500 MW
- Electrolyzer system operated at ambient conditions
- Power: Via grid from nuclear or Power Purchase Agreements
- Location: France
- Sale of O_2: €24.5/t

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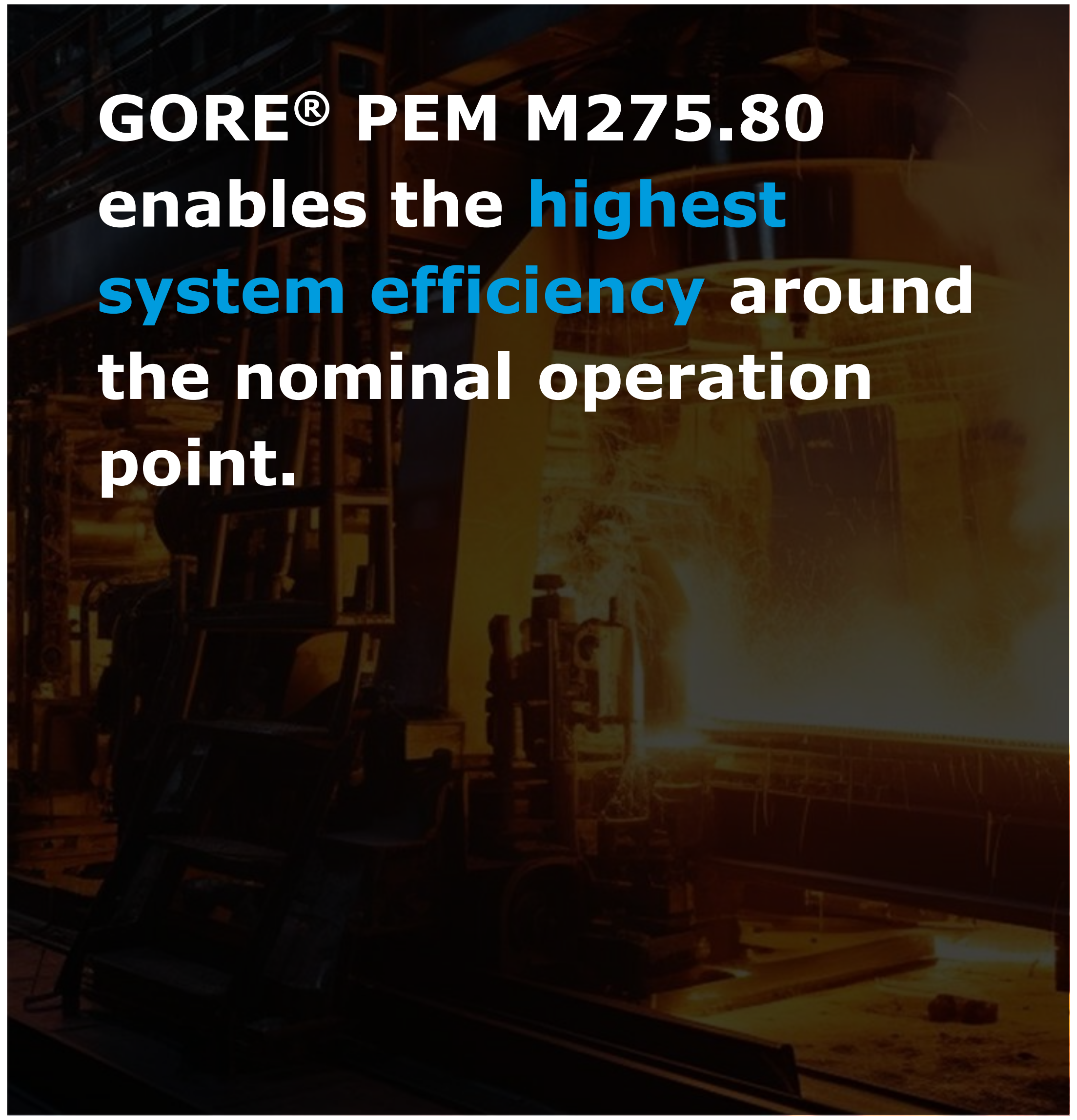
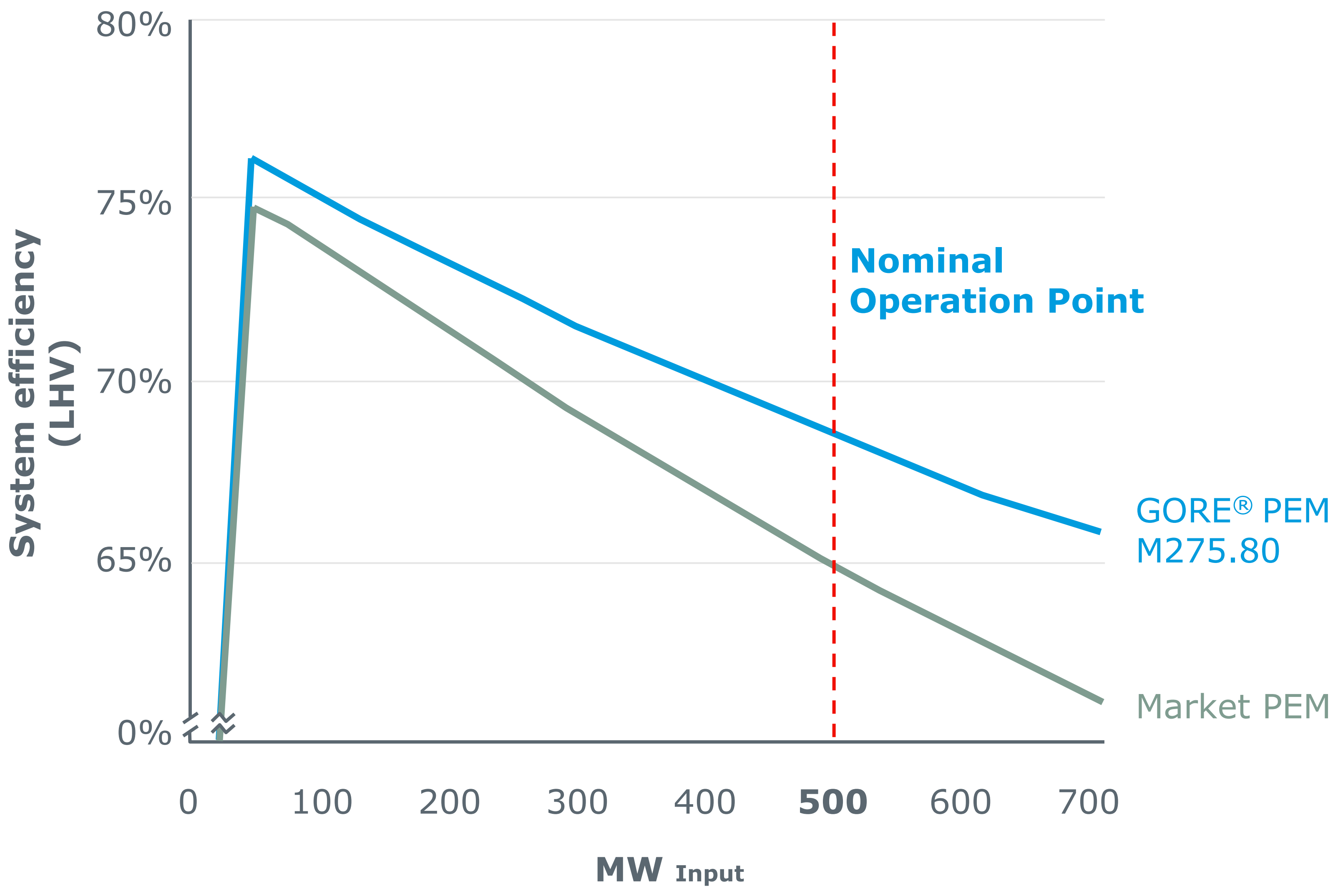
Use Case #2: Steel Mill

Use-case definition | **System output** | LCOH output | LCOH savings / year





Overall efficiency (LHV)

GORE® PEM M275.80	**68.3%**
Market PEM	**64.7%**

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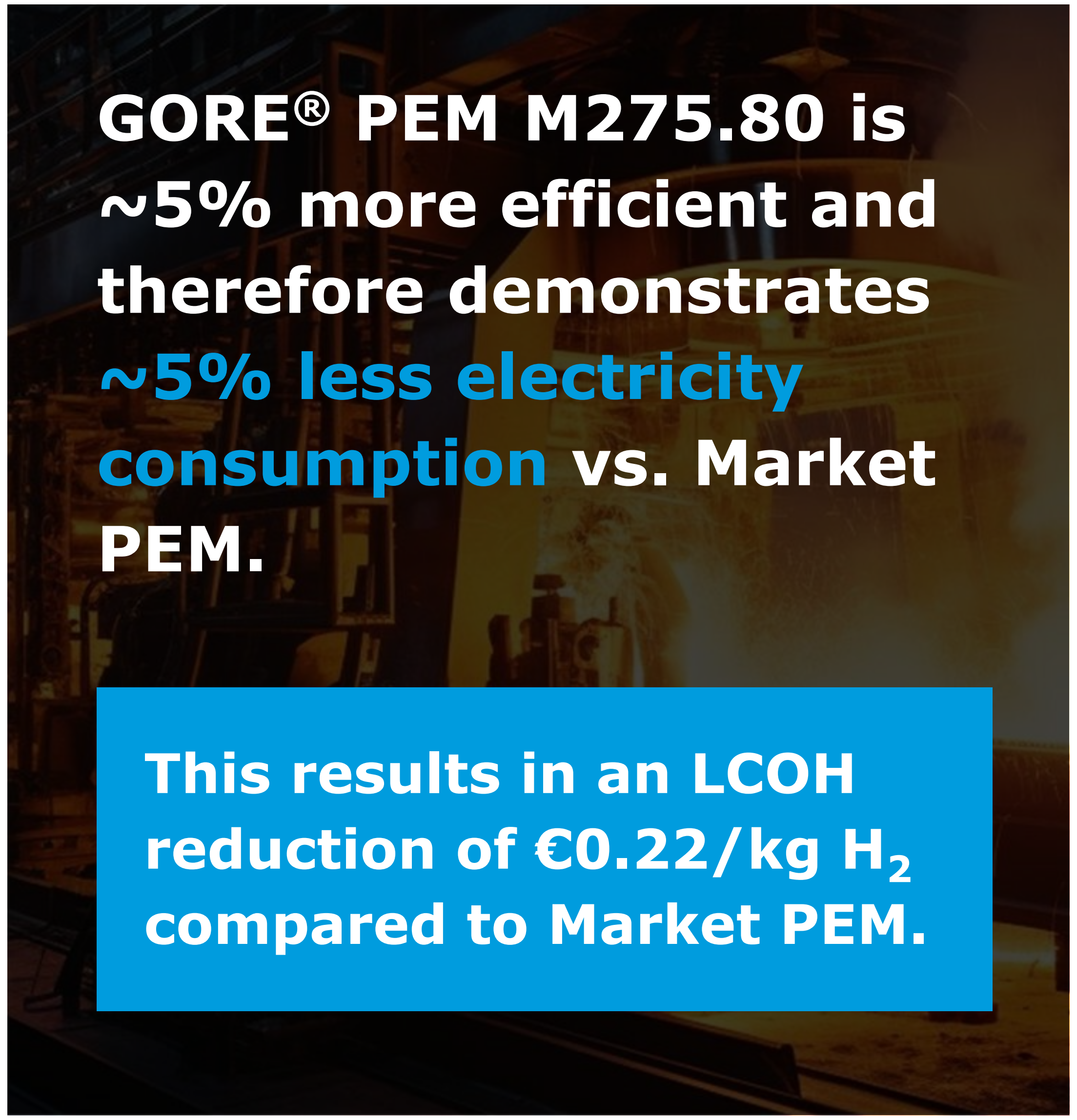
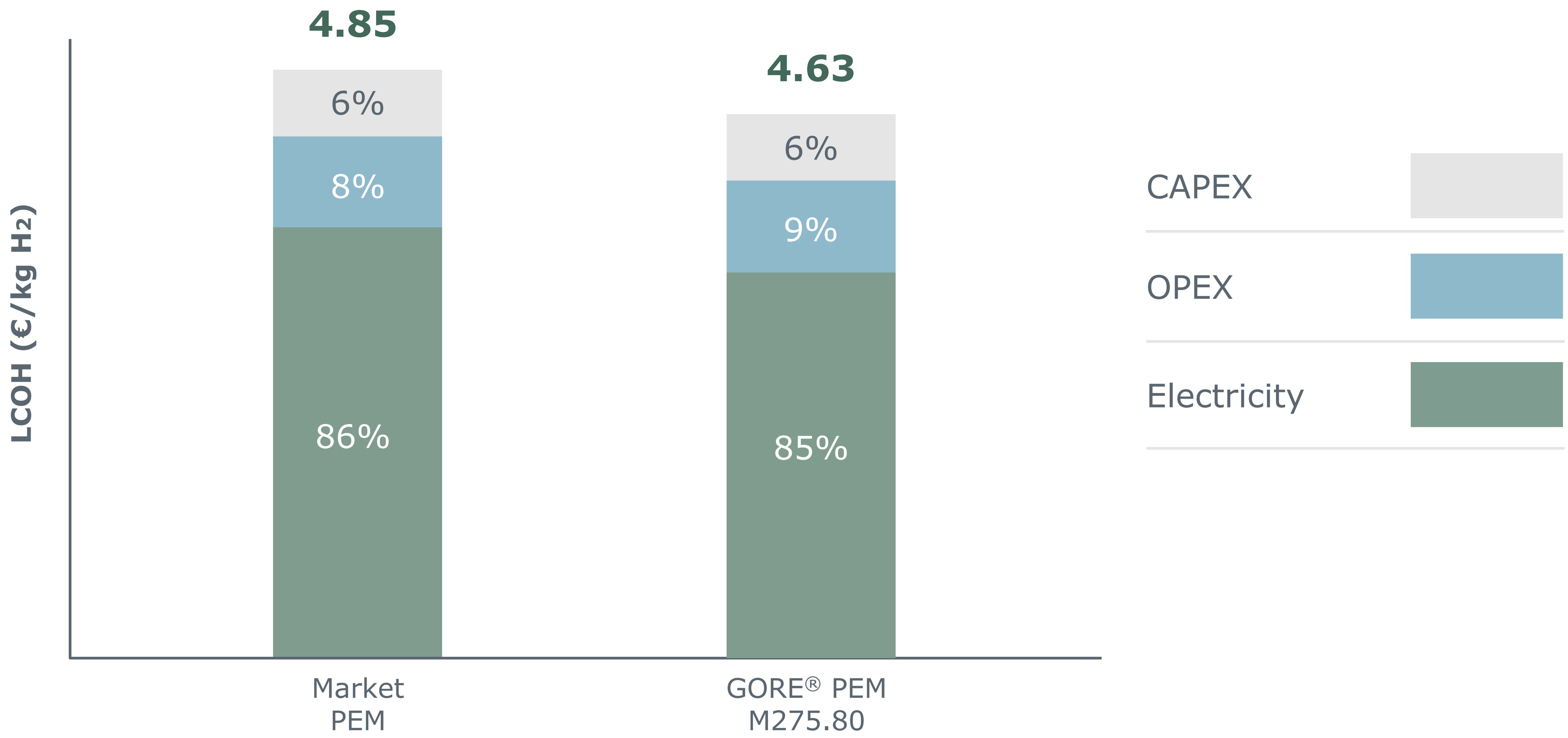
Use Case #2: Steel Mill

Use-case definition | System output | **LCOH output** | LCOH savings / year



GORE® PEM M275.80 is ~5% more efficient and therefore demonstrates ~5% less electricity consumption vs. Market PEM.

This results in an LCOH reduction of €0.22/kg H_2 compared to Market PEM.



Use Case #2: Steel Mill

Use-case definition | System output | LCOH output | **LCOH savings / year**

€18.7 million

For ~85,000 tons produced annually at €4.63/kg H_2, this translates to annual electricity savings of **€18.7 million with GORE® PEM M275.80** compared to Market PEM.

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In summary

1 Ambitious decarbonization goals are at risk as **high costs of green hydrogen are not affordable** for off-takers.

2 **Electricity** costs are the **primary cost driver**.

3 Highly conductive PEMs can significantly improve voltage efficiency and therefore **reduce electricity costs**.

4 Modelling various use cases showed that Gore's high-efficiency PEM M275.80 **reduces LCOH by up to 5%**.

5 Further **enhancements in proton resistance and hydrogen permeation resistance** will drive LCOH even lower.

6 Therefore, innovations such as **unique ionomers, additives and a thin & durable membrane construction** play a pivotal role.

GORE'S PEM PROMISE

Gore's PEM promise

How Gore supports the scaling of green hydrogen production

Multi Gigawatt global production capacity of PEM with multiple production lines

Proven supply security, process stability + consistent high-quality

Product leadership through continuous product advancements to enable lower cost of hydrogen

Partnership and collaboration to maximize system performance and durability in a complex system

Together, improving life.

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THANK YOU.

Visit our Clean Energy Experts in Hall A3, Booth C70.

Download the presentation after the event.

Download the white paper.

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